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Final Technical Report

For Project Entitled

"Analysis and Interpretation of High Energy Cosmic Rays Measured on Spacelab-2"

NASA Grant NAGW-1311

1 January 1988 - 31 December 1990

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FINAL REPORT

NASA GRANT NAG W-1311

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1. Introduction

Under the contract with NASA's Marshall Space Flight Center (NAS 8-32828) the University of Chicago designed, built and delivered the CRN instrument for flight in the Spacelab-2 configuration. The instrument was flown from July 29 to August 5, 1985 on the Space Shuttle Challenger. The performance of our experiment was entirely successful and we reached our scientific goals.

The contract included funds for the first year of data analysis. Further data analysis was carried out under the grant NAG W-1311 which ran from January 1, 1988 through December 31, 1990, and on which we report.

The final product of this grant are the published scientific papers with the results from the experiment. We attach copies of the papers that have been published to date, and which we consider the most important part of this report.

However, in order to put them into context we give a brief account of the project as a whole for which the grant covered the final phase.

2. The Staff

The original proposal for this experiment was submitted in 1976 in response to AO-OSS-2-76 by P. Meyer and D. Müller as Co-PI and James Lamport as Co-I. Shortly after selection for flight in 1977 the scientific team was enlarged by Jacques L'Heureux and Simon Swordy as Co-I. Lamport, after his retirement, resigned from his role as Co-I.

L'Heureux (Senior Research Associate), aside from his individual contributions, took on the role of Managing Project Scientist. Don Bonasera (Senior Electronics Engineer) was Project Engineer and head of the electronics group (E. Drag, W. Harvey, W. Hollis); W. Johnson (Senior Mechanical Engineer) carried the responsibility for mechanical design and fabrication; Roger Ray (Supervisor, Systems Analyst) headed the software and programming group (J. Berger, L. Glennie) that produced software for the onboard processor and the ground support equipment for preflight tests and flight.

3. Design and Fabrication

The above group, under the guidance of the investigators, carried out the design and fabrication of the instrument. Most of the components (mechanical and electrical) were

produced at the University's Central Shop and by the electronics group with the help of capable graduate and undergraduate students. Special components (instrument container, valves, etc.) were procured from vendors.

Two important technical advances should be reported here. The six large multiwire proportional chambers that are part of the transition radiation detectors have thin 2m x 2m mylar windows. Gas must continually stream through them. To avoid any bulging of the windows the pressure difference between chambers and instrument shell had to be kept below 10^{-5} atm. A special sensitive pressure control gauge was developed in the laboratory that fulfilled this requirement and worked perfectly through the flight (see attached instrument publication).

The second important advance was the recognition that the radiator for the transition radiation need not be made of large numbers of polyethylene foils as was originally proposed, but could, without loss of efficiency, be composed of thin fibers. Such fibers of polyolephin are used commercially for thermal insulation, are inexpensive, and can readily be packed into layers. With accelerator runs (synchrotron of the University of Bonn and Fermi National Accelerator Laboratory) we could verify that fibers can replace foils as radiators with no loss in performance.

4. Accelerator Calibrations

(a) The Multiwire Proportional Chambers (MWPC)

The CRN instrument is capable of observing individual cosmic ray nuclei of the elements from Boron ($Z=5$) to Nickel ($Z=28$). To cover this wide dynamic range requires optimization of the multiwire chamber parameters. In particular one has to choose the gas mixture and the best operating high voltage. Beams of energetic heavy particles from the Berkeley Bevalac were used to carry out this optimization, using several prototype chambers.

(b) The Transition Radiation Detector (TRD)

The use of TRD's for measuring the energy of heavy nuclei is an entirely new technique, used for the first time in this experiment. Since there exist no accelerators that produce heavy nuclei of sufficient energy, the calibration of the TRD had to be done with singly charged particles, made available to us at FNAL (Fermilab) and at the electron synchrotron of the University of Bonn, Germany. A prototype TRD with the same number of radiators and MWPC's as the flight unit was constructed and exposed to beams of protons, π -mesons, μ -mesons, and electrons. In this manner, a complete calibration could be obtained. In-flight check of the calibration was possible over a limited range of energies using Fe nuclei.

5. Environmental Tests

(a) Mechanical: pressure, vibration, acoustic, temperature

The instrument container and gas containers were designed to meet safety regulations for manned flight. The instrument container that must withstand 1 atm. during flight was

tested to 2 atm. Electronic subassemblies and critical parts like gas valves were vibration tested using the laboratories facility. E&M tests and temperature tests were made on subassemblies.

The completed instrument was shipped to GSFC where integrated E&M tests and exposure to acoustic environment could be carried out in large size test chambers. The instrument passed all these tests without requiring any modification.

6. Preflight Performance Tests

Performance tests of the completed instrument are difficult to carry out in the absence of a beam of relativistic heavy nuclei. The only particles readily available in a laboratory at sea level are cosmic ray μ -mesons. Increasing the gain of several detectors and their electronics it is possible to bring the μ -meson signals into the range of the instrument and to carry out rough performance tests. This was done in the laboratory at Chicago and after shipment at KSFC. Preflight performance tests were complicated by the fact that the instrument had to be delivered and enclosed in its container more than a year prior to launch. Onboard electronics therefore became inaccessible and all communications with the instrument had to be carried out through the GSE and onboard processor. This required design and construction of a considerable amount of additional electronics, thus increasing complexity as well as cost. During the flight the MWPCs must be flushed with the very expensive gas xenon to operate correctly. During the preflight phase this gas was used at only a few occasions to test proper performance. Maintenance and cleanliness of the chambers was achieved by continuous flow of an inexpensive gas mixture. The preflight period with periodic performance tests revealed no major problems and integration into the spacecraft was achieved without encountering difficulties.

7. Activation, Flight Performance, Data Collection

After an aborted attempt to launch Spacelab-2 in early July 1985, the launch took place on July 29, and the spacecraft returned on August 5. Activation of the CRN electronics, gas flush of the MWPC followed the prepared timeline. After 14 hours of flight the instrument was fully operational, and complete data were received. The first day was used to optimize parameters like high voltage levels, discriminator levels and the final choice of the master coincidence. The instrument worked continuously until the end of the flight. Occasional crashing of the onboard processor could always and rapidly be reset and caused little loss of data. The cause for these crashes was identified and corrected after return of the instrument and was found to be due to a hardware timing error. The biggest loss of data for this experiment, where long exposure is crucial, came through competing requirements for spacecraft attitude for the different experiments, and the times spent in the radiation belts due to the choice of a high latitude orbit. Out of the total flight time of 179 hours, only 78 hours were useful to our datataking.

8. Postflight Instrument Check – Present Status

After unloading at KSFC the instrument was trucked back to the University of Chicago and thoroughly tested. It was found in excellent operating condition. The instrument was

partially disassembled for safe storage and maintenance and is awaiting the opportunity for a long duration flight.

9. Data Analysis and Scientific Results

Data analysis, started after the return of the instrument. A full account of the scientific results is given in the published papers, copies of which are attached and are part of this report. CRN was an extremely successful experiment which benefited greatly from the enthusiastic support by the scientists, the technical staff and the management groups at the University of Chicago, at MSFC and at KSFC.

The data analysis began immediately after receipt of the final data tapes. These were converted into scientific tapes after a variety of cuts and selection criteria were defined and applied. An instrument model and calibrations provided the criteria. Six papers were published in refereed scientific journals to date. Several additional papers are part of the proceedings of international conferences. The papers, and the contributions to conferences were prepared with funds from grant NAG W-1311.

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